Nonlinear Cyclic Transient Dynamic Analysis for Bladed Disk Tip Deflection

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Long Abstract

Introduction

Accurate prediction of blade tip displacement is critical to prevent serious rub and wear while maintaining high performance for jet engine fan, compressor and turbine blades. During stall and surge events, the fan and front stage compressor blades' large dynamic deflection shows strong nonlinear behavior. Convectional linear estimation based on mode shapes cannot accurately predict the tip clearance during these events.

Full wheel transient dynamic analysis to predict the nonlinear tip deflection is computationally expensive. Cyclic sector model has been widely used in investigating linear vibration problems and provided satisfactory predictions for bladed disks harmonic response under small deflection. However, for blade undertaking large deflections, the force-deflection relationship exhibits strong nonlinear characteristics, and linear deformation based cyclic sector model is no longer able to provide accurate prediction. Unfortunately, most commercial finite element software including ANSYS currently does not have nonlinear forced response capabilities for cyclic sector models. In this work, a finite element based nonlinear transient dynamic method is developed for cyclically symmetric structures and numerically validated against full wheel analysis. The method will be used to predict large deflection of bladed disks under traveling wave excitation and high speed spinning.

Methods

The Lagrangian formulation based finite element equations are used to solve the equation of motion for nonlinear deformation. For periodic excitation, force and displacement are represented as the sum of spatial harmonics. The finite element solution then results in a search of the displacement coefficients provided with the force coefficients for each harmonic respectively. The dual sector model (Fig. 1) is used to solve for harmonic coefficients by taking advantage of the geometric cyclic symmetry. The boundary coupling equations imposed on the high side and low side of the sectors for each nodal diameter enable the interaction between the sector and its neighboring sectors. In addition, the stress stiffening effects due to high speed spinning is included in the modeling process. Since the nodal diameter (usually equals zero) of spinning deformation is different from the one of excitation force, the deformations of the sector due to different nodal diameters are decoupled by modifying the dynamic cyclic boundary conditions. In the search of the maximum deflection, we excite the blade with traveling wave force which is the most customary in analysis of vibrations of bladed disks due to the bladed disk rotation with constant speed while preserving their spatial distribution. The method is verified with the full wheel bladed disk simulation. The results suggest high fidelity and efficiency of the method and its promising applicability in analyzing real bladed disks.

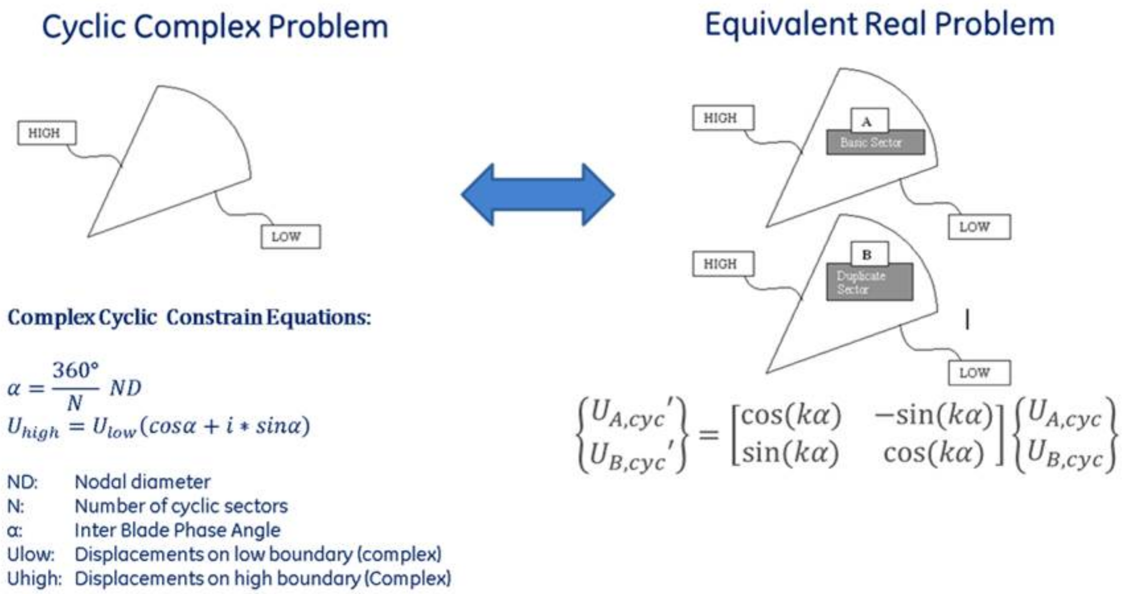

Figure 1. Dual sector approach for cyclic model used in ANSYS.

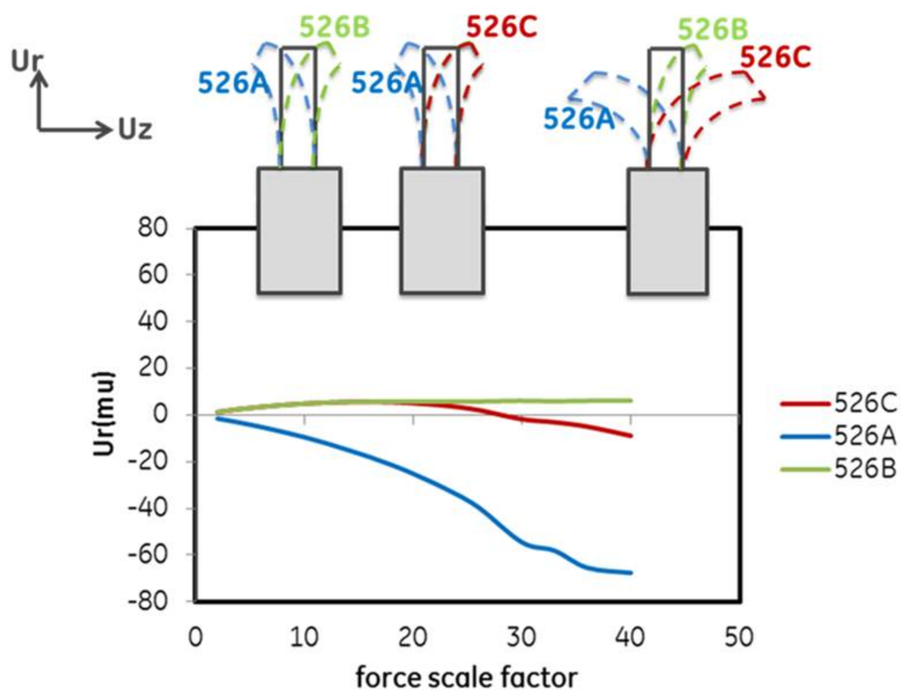

Figure 2. Nonlinear cyclic dynamic tip radial deflection vs. forcing demonstrated on an academic blisk model.